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AUTHOR Winn, Bill
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ABSTRACT

The instructional effectiveness of diagrams has been substantiated by research; however, research findings are limited for the identification of the conditions that are necessary for learning from diagrams. The study reported in this paper investigated certain properties of diagrams and how they relate to cognitive processes that students use when learning from them. Specifically, the effect of varying the amount of detail in elements in a diagram on students' ability to perform simultaneous and successive processing tasks was explored. The two tasks required high school students (N=41) either to study and draw from memory an electronic circuit diagram (simultaneous task), or to study and remember a list of the individual components in the circuit in a particular order (successive task). It was found that students who saw diagrams with symbols performed better on the sequence task and worse on the pattern task than the students who saw the diagrams with squares, whose performance on the two tasks was exactly the opposite. A subsequent experiment found that requiring the students to label the elements in the diagram did not interfere with their ability to remember the patterns of the components. (ML)

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Simultaneous and Successive Processing of Circuit Diagrams Having Different Amounts of Detail.

Bill Winn

University of Washington.

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Abstract

Forty-one high school students studied a series of five circuit diagrams. These either showed the electronic components as standard symbols or as squares. Each component was labelled and numbered. Students either had to remember the pattern of the elements in the diagram and draw it from memory, or they had to remember the elements in sequence. It was found that students who saw diagrams with symbols performed better on the sequence task and worse on the pattern task than the students who saw the diagrams with squares, whose performance on the two tasks was exactly the opposite. A subsequent experiment found that requiring the students to label the elements in the diagrams did not interfere with their ability to remember the patterns of the components. These results were interpreted within the framework of simultaneous and successive processing theory.

There has been a large amount of research demonstrating the instructional effectiveness of diagrams. A lot of this has been motivated by a concern for designing effective science textbooks, where, typically, diagrams accompany text (Holliday, 1975). However, only a relatively small portion of this research has explained the reasons for this effectiveness in terms of the way in which the characteristics of diagrams convey meaning and engage those cognitive processes that lead to learning. The result has been that the majority of studies have told us <u>if</u> diagrams are effective in different instructional roles, not <u>why</u>. The necessary conditions for learning from diagrams, that are fundamental to the construction of instructional theory (see Clark, 1983), have largely escaped study.

The study reported here investigated certain properties of diagrams and how they relate to cognitive processes that students use when learning from them. Diagrams can be thought of in terms of the elements that they contain, and the relationships among these elements (Winn & Holliday, 1982). The elements in an electronic circuit diagram, for example, would be the individual components, such as resistors, transistors and diodes, that make up the circuit. The relationships among these would be expressed in the way each component is connected to the others. The meaning of a diagram for the student is derived both from the way in which the elements are represented and from the pattern formed by the arrangement of the elements in relation to each other (Knowlton, 1966; Szlichcinski, 1980). In the circuit diagram, the elements (components) might be shown as conventional electronic

symbols, or as verbal labels. The pattern formed by linking the components together by means of lines representing electrical connections might be to scale or highly schematized.

There is evidence that varying the way in which the elements in a diagram are represented and the patterns that they form has an effect on the way students perform certain tasks. Showing the elements in flow diagrams as pictures improves students' ability to identify the elements correctly and to remember them in particular sequences. Winn (1982) used a flow diagram to teach grade nine students the evolution of dinosaurs. Showing the animals as small drawings rather than as verbal labels improved performance on a test requiring the students to identify the dinosaurs and also on a test of the evolutionary sequence. However, the inclusion of pictures did not improve performance when the task was to classify the dinosaurs into large superordinate categories or by geological period. Similarly, Holliday, Brunner and Donais (1977) reported superior performance on a comprehension test of biochemical cycles for low-verbal students who had learned the content from flow diagrams whose elements were shown as pictures rather than as verbal labels. Kulhavy, Schwartz and Shaha (1983) found that features on maps, shown as pictures, were easier for students to recognize and recall than when the features were shown as symbols.

The effects of the variation of pattern is likewise determined by the tasks that the students are expected to perform. In the dinosaur study, mentioned above, some students saw flow diagrams in which the natural left-to-right evolutionary sequence was reversed on the page. This made it more difficult

for the students to learn the sequence in which the animals evolved, and reduced their success at classifying them into superordinate families. However, the reversal of the diagram did not affect their ability to identify the animals. Bartram (1980) found that a schematic map of bus routes was more effective than a regular street map at helping students solve problems about the best route to take to get from one point to another. This was presumably because, when planning how to get from one place to another by bus, one is concerned with the sequence of bus stops and transfer points rather than whether the route map is to scale or not. The simplified pattern of a schematic map would emphasize this information at the expense of other, less relevant, material.

These studies suggest that, depending upon how the elements and patterns are presented, diagrams can help students understand two-dimensional structural relationships among concepts, and one-dimensional linear sequences of concepts. In two-dimensional space, the structural relationships among the concepts can be made very specific, and the general organization of the content can therefore be made very clear (Jonassen and Hawk, 1984). Thus, diagrams are good at explaining complex relationships in processes, such as the Nitrogen cycle (Koran and Koran, 1980) and other biochemical cycles (Holliday, 1976). Through the order in which elements appear, from left to right and top to bottom, or through the use of graphic devices such as arrows, diagrams are also good at describing sequences of concepts, such as the evolution of dinosaurs, finding your way by

bus, and the stages of insect metamorphosis (Winn, 1981).

The learning of two-dimensional patterns and one-dimensional sequences in diagrams calls upon different cognitive processes. Das, Kirby and Jarman (1975, 1979) have described two modes of cognitive processing that they call "simultaneous" and "successive". Simultaneous processing requires that all of the information needed to perform a task be accessible to the student at once. Thus, the student who has to learn the structural relationships, in two dimensions, among elements in a diagram of the Nitrogen cycle has to be able to see all of the elements in the diagram simultaneously and to be aware first and foremost of the overall pattern they form. Successive processing simply requires that the elements adjacent to each other in a sequence be accessible at one time. In order to learn the sequence in which the dinosaurs evolved, students' attention would have to be directed to each element in turn so that they could link each animal with the one that preceded it and the one that followed to construct a chain. The way the elements and patterns in diagrams are presented will therefore affect how easy it is to perform simultaneous and successive processing. When attention is drawn to individual elements by making them distinctive, successive processing will be facilitated. When attention is drawn to the overall pattern by de-emphasizing the individual elements, then simultaneous processing will be facilitated.

This study investigated the effect of varying the amount of detail in elements in a diagram on students' ability to perform simultaneous and successive processing tasks. The two tasks required students either to study and draw from memory an

electronic circuit diagram (simultaneous task), or to study and remember a list of the individual components in the circuit in a particular order (successive task). Since the simultaneous task required students to learn the general pattern of the elements, it was expected that increasing the detail in each indiviual element would provide information that was unnecessary for the task, and would therefore interfere with students' ability to draw the diagram. On the other hand, the successive task required students to remember the identity of each component individually. It was expected that the addition of detail would make the components easier to distinguish from each other and would therefore facilitate performance on the list task. The amount of detail in the elements was varied by presenting the components either as labeled electronic symbols or as labeled squares. The symbols would be redundant for the simultaneous task, and were expected to impede performance. For the successive task, however, the symbols would help students distinguish between one component and the next and would make it easier for them to learn the sequence of components. This differential effect of the amount of detail on the performance of the two tasks would be apparent in a statistically significant interaction between task and type of diagram.

Experiment 1.

Method

Design.

The design of experiment one was a two by two by five factorial. The two between subjects factors were task (draw diagram, list components), and format (symbols, squares). Trial (five different diagrams) was a within subjects factor.

Subjects.

The subjects were 41 grade 10, 11 and 12 students from a large urban high school. They were assigned randomly to the four treatments.

Materials.

The circuit diagrams were all portions of larger diagrams taken from repair manuals or general documentation for electronic equipment. Each diagram contained from 11 to 18 components, and each contained at least one of: resistor, transistor, diode, capacitor, ground. These were reproduced on sheets of 8 1/2 by 11 paper, one diagram per sheet. Each component was labelled with its initial letter, and a key to the name of each was placed below the diagram in a list. In order to make it possible for students to learn the components in a prescribed order, each component was also numbered. As far as possible, the sequence of numbers ran from left to right, top to bottom across and down the page. For the "symbols" treatment, each component was represented by its conventional symbol. For the "squares" treatment, the component was represented by a square. Figures 1 and 2 show an example of each type of diagram.

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Figures 1 and 2 about here

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In order to determine whether any subjects were familiar with the symbols for electronic components, a brief pretest was prepared where symbols had to be matched with their names.

A package of materials was prepared for each student. First was the pretest, followed by instructions which told the subject whether to memorize the components in order, or to learn the diagram which would have to be drawn. Subjects who were to draw the diagram were instructed not to label or number the components. Next came six circuit diagrams. (The first was used as practice and was not scored.) After each diagram was a blank sheet of paper on which the subject drew the diagram or wrote the list.

Procedure.

The experiment was conducted in four separate classes. The materials were distributed randomly. After a brief introduction, in which the experimenter engaged the students in general conversation about electronics as a hobby (very few students were in fact hobbyists) and what circuit diagrams were, the subjects took the pretest. This was scored immediately and discussed briefly with the students so that they would all have some familiarity with the symbols, which, as it turned out, all but a very few were completely unfamiliar with. Those who were familiar with any number of symbols were excluded from the analysis.

The subjects then read the instructions and did the practice diagram. Great care was taken to make sure that the subjects

understood what they were expected to do, and again it was stressed that symbols should not be labelled or numbered. Subjects then studied each diagram for three minutes, and were given three and a half minutes to draw it or make their list of components.

When they had finished all of the diagrams, the materials were collected. The whole experiment took approximately one hour.

Data Analysis.

The drawings and lists were scored as follows. For the drawings, a point was given if a symbol or square was placed in the correct position in the diagram. In the symbol condition, a point was given if any component was in the position. This was intended to remove the advantage subjects seeing squares would have by virtue of their not having to remember the name of each component. In fact, in just about every case, the components were the correct ones. Considerable latitude was given regarding the absolute position of the components, with relative position being more important. A point was subtracted for each extra component added to the diagram. For the lists, a point was given for each component in the correct position in the list. In the event that one or more components was omitted in the middle of the list, the score was calculated by combining the longest "runs" of components in the correct order. Because of the unequal number of components in the five diagrams, all raw scores were converted to percentages for analysis.

These data were analyzed using a two by two by five repeated measures analysis of variance. When interactions were

significant, analysis of variance for simple main effects was performed following the procedure recommended by Winer (1962, pp. 309-312).

Results.

Means and standard deviations of scores, collapsed over trials, are presented in table 1. Both main effects were

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Table 1 about here

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significant. For format, $F(1,39) = 5.42$, $p<.05$. For task, $F(1,39) = 18.33$, $p<.001$. The task by format interaction was also significant, $F(1,39) = 15.30$, $p<.001$. Analysis of simple main effects showed that, of the subjects who had to draw the diagrams, those who saw squares performed significantly better than those who saw symbols, $F(1,39) = 19.62$, $p<.001$. Of the subjects who had to make the lists of components, while, as predicted, those who saw symbols performed better than those who saw squares, this performance was not significantly superior, $F(1,39) = 1.24$, $p>.05$.

The within-subjects factor was also significant, $F(4,156) = 7.66$, $p<.001$. This indicated that the tasks were not of equal difficulty over the five diagrams, which was to be expected given the different number of components in each.

These results give support to the hypothesis that the presence of details, as symbols, in circuit diagrams would hinder students drawing the diagrams from memory, a task that required simultaneous processing. The failure of the format comparison for students writing lists to reach significance was probably due to

a ceiling effect. The scores certainly seem to indicate this, being 89% for squares and 96% for symbols. Given the time for its completion, the list task turned out to be extremely easy for the students in both treatment groups. A second experiment was therefore conducted in which steps were taken to remove the possibility of a ceiling effect for the list task.

Experiment 2.

The second experiment was a replication of the list-task portion of the first experiment with the difference that subjects were given less time to study the diagrams and write their lists.

Method.

Design.

The design of experiment two was a two by five factorial involving format (symbols, squares) as a between subjects factor and trial (the five diagrams) as a within subjects factor. The dependent measure was the number of components correctly listed in order.

Subjects.

Subjects were 27 grade 10, 11 and 12 students from a high school in a mid-sized rural community. They were randomly assigned to the two treatments.

Procedure.

This was the same as the one followed in the previous experiment, with the exception that subjects studied the diagrams for one and a half minutes and were given one and a half minutes to write their lists.

The materials and scoring procedures were the same as those

used in experiment 1.

Results.

A significant main effect for format was found, $F(1,25) = 4.40$, $p<.05$. The mean score for subjects seeing symbols was 85.33, and the mean for subjects seeing squares was 75.40. This suggests that, with the ceiling effect removed, studying diagrams with more detail in their elements does indeed help students learn sequences of components.

Experiment 3.

In the first experiment, a few subjects in the simultaneous task group recalled and wrote the labels attached to the components in the diagrams. This suggested that, even though they were told not to, and even though their scores were based on the pattern of elements, not on whether the components were in the right place, some students were learning the names of the components as well as their positions. This would have increased their memory load and reduced their performance. The purpose of experiment three was to determine whether, in fact, requiring subjects to remember the labels as well as the components in their drawings of diagrams would interfere with their ability to remember the patterns that the elements formed. To this end, the drawing portion of experiment one was replicated, without the list task, and with the addition of a group who had to label their diagrams as well as draw them.

Method.

Design.

The design was a two by two by five factorial. Between subjects factors were task (draw diagram, draw and label diagram)

and format (symbol, square). Trial was a within subjects factor.

Subjects.

Subjects were 29 grade 10, 11 and 12 students from a high school in a mid-sized rural community, who were randomly assigned to the four treatments.

The materials and procedure were the same as in the first experiment.

Scoring.

For the subjects who had to label their diagrams, each drawing was scored twice. First, one point was given for any component in the right position, as in experiment one. Second, a point was given only if the right component, correctly labelled, was in the correct position. Two separate analyses of variance were performed on these data.

Results.

Means and standard deviations are presented in table 2. For the first set of scores (labels not scored), no significant

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Table 2 about here

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differences were found. For format, $F(1,27) = 1.94$, $p>.05$. For task and for the task by format interaction, $F<1$. When data were derived from scores for correct components and correct labels, task approached significance, $F(1,27) = 3.13$, $p<.1$. Format was not significant, $F(1,27) = 1.54$, $p>.05$, nor was the interaction between format and task, $F<1$.

These results suggest that requiring students to label the

elements in a diagram does not reduce their ability to remember its pattern. However, there is a suggestion, in the marginally significant difference for task when the accuracy of the labels was also scored, that, while not affecting simultaneous processing, the required labelling might not be all that accurate. However, further research is required before this can be concluded with any certainty.

General Discussion.

The results obtained from these three experiments lead to three observations. First, the general hypothesis of the study was supported. The diagrams with more detail in their elements made it easier for students to perform a successive processing task, while those with less detail in their elements facilitated simultaneous processing. The former type of diagram drew attention to the distinctiveness of each individual element, making it easier to remember them in sequence. The latter type of diagram minimized the distinctiveness of each element, making it easier for the students to learn the "big picture" made by the patterns that the elements formed.

The second observation is that the simultaneous task was not affected by requiring students to remember the names of the elements as well as their position. This is somewhat surprizing, as one would expect the additional requirement would make the task more difficult to perform. Two explanations for this finding are possible. Either all of the students learned the names of the components in the circuit diagrams, while only those who were asked to wrote them down. Or, indeed, it does not really make any

difference if students are required to remember more. Perhaps requiring the students to encode each element as a word as well as a symbol in a pattern somehow made up for the deficit in performance resulting from the extra load on memory. The advantages of such "dual coding" are well established (Paivio, 1971, 1983). More research is needed to resolve this issue.

Finally, the study draws attention to the importance of considering how the different characteristics of diagrams interact with students' ability to perform certain learning tasks. This study has provided evidence that the way the amount of detail in the elements in diagrams is varied affects students' ability to perform simultaneous and successive processing tasks. This relationship between amount of detail and type of processing is but one of many that exist between diagrams and cognition. It behooves us to study these in detail rather than simply to assess whether or not the presence of a diagram in instructional materials affects learning outcomes. Results of this latter, and unfortunately most common, type of research will not help designers of textbooks and other instructional materials improve their products because they will not be able to indentify what it is in the diagram that engages the particular processes students need to use i~n order to learn.

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Table 1.

Mean Scores from Experiment 1.

		Task		
		Draw Diagram	Write List	
Format	Square	88.18	89.71	89.02
	Symbol	62.34	96.26	77.09
		72.92	92.83	

Table 2.

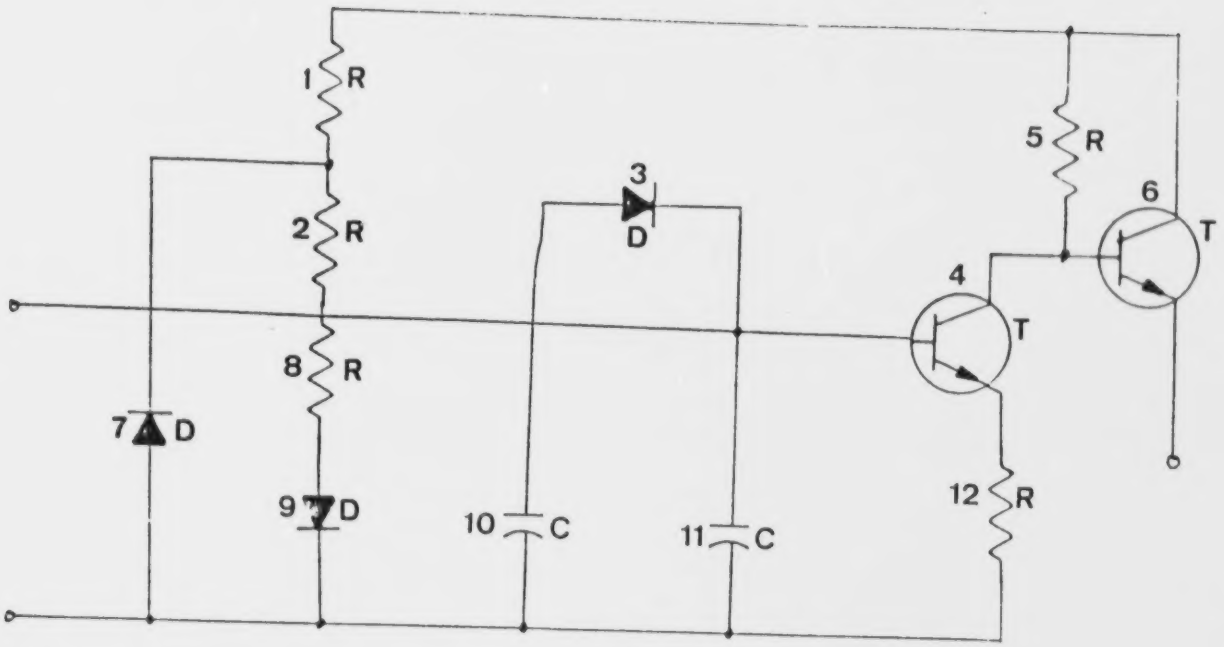
Mean Scores from Experiment 3.

1. Labels not Scored

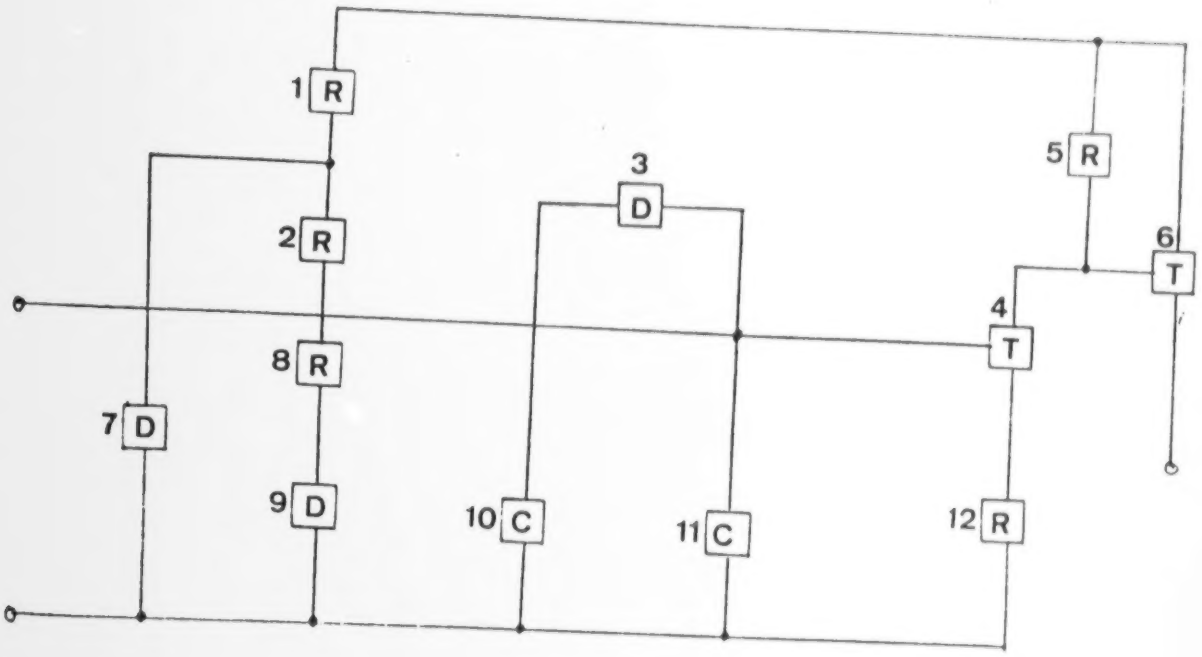
	Task		
	Not Labelled	Labelled	
Square Format	83.71	81.40	82.48
Symbol	75.87	75.69	75.79
	79.30	78.73	

2. Labels Scored

	Task		
	Not Labelled	Labelled	
Square Format	83.71	72.87	77.93
Symbol	75.87	66.60	71.81
	79.30	69.95	



C CAPACITOR
D DIODE
G GROUND
R RESISTOR
T TRANSISTOR



C CAPACITOR
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T TRANSISTOR